Kepler: a space mission to detect earth-class exoplanets

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ABSTRACT

With the detection of giant extrasolar planets and the quest for life on Mars, there is heightened interest in finding earth-class planets, those that are less than ten earth masses and might be life supporting. A space-based photometer has the ability to detect the periodic transits of earth-class planets for a wide variety of spectral types of stars. From the data and known type of host star, the orbital semi-major axis, size and characteristic temperature of each planet can be calculated. The frequency of planet formation with respect to spectral type and occurrence for both singular and multiple-stellar systems can be determined.

A description is presented of a one-meter aperture photometer with a twelve-degree field of view and a focal plane of 21 CCDs. The photometer would continuously and simultaneously monitor 160,000 stars of visual magnitude \leq 14. Its one-sigma system sensitivity for a transit of a twelfth magnitude solar-like star by a planet of one-earth radius would be one part in 50,000. It is anticipated that about 480 earth-class planets $(0.5\leq M\leq10~M~)$ would be detected along with 140 giant planets in transit and 1400 giant planets by reflected light. Densities could be derived for about seven cases where the planet is seen in transit and radial velocities are measurable.

Keywords: earth-class planets, extrasolar planets, photometry, planet detection, transit method

1. INTRODUCTION

The past three years have seen a major leap in the detection of extrasolar planets. Since antiquity, people have speculated as to whether Earth is unique and whether there are other worlds in the cosmos. This all changed in 1994 when Wolszczan¹ confirmed his earlier detection of three planets orbiting a pulsar and in 1995 when Mayor and Queloz² reported detection of the first extrasolar planet orbiting a solar-like star. Since then seven additional planets (Msin i < 7 M_{Jup}) have been detected^{3, 4, 5, 6, 7}. The year of 1996 was the first time in history that more planets were known outside our solar system than inside. A summary of the efforts leading up to and including the recent results are presented elsewhere ^{8, 9, 10}. Since then the goal of detecting extrasolar planets that could be habitable has been enunciated in many planning documents^{11, 12, 13} including the *NASA Strategic Plan*¹⁴.

Aside from the pulsar planets, all of the planets detected so far are on the order of Jupiter in mass or larger. The next major step will come with the detection of earth-class habitable planets. Several approaches to the detection of earth-class planets are possible including direct imaging, microlensing and transit detection. However, only the later has matured to the point where a low-cost mission can be implemented at this time that will provide statistically meaningful results on the distribution and abundance of earth-class and larger planets around a wide variety of stars. For each detection by the transit method the orbital period and decrease in brightness is measured. The planet size, the semi-major axis and the planet's characteristic temperature¹⁵ can be calculated by incorporating information on the parent stellar type, enabling one to answer the question as to whether or not the planet is in or near the habitable zone. In addition, once detected follow-up investigations can search for giant companions using Doppler spectroscopy and infrared measurements can determine the amount of zodiacal light in each system found to have an earth-class planet.

2. EARTH-CLASS AND HABITABLE PLANETS

There have been numerous debates and discussions over what constitutes a planet. Lissauer¹⁶ presents an excellent review "On The Diversity Of Plausible Planetary Systems." Recall that the word is from the Greek meaning wanderer and is not based on its origin or character. For this mission we are not concerned with the distinction between a planet and a brown dwarf. Rather, we are concerned with terrestrial or earth-class planets. We will use the definition for a habitable or earth-class planet that was used in the ExNPS report¹⁷"...as a solid body with a mass between ~0.5 and ~10 Earth masses at a distance from its parent star such that the planet's surface temperature and atmospheric pressure are consistent with the presence of

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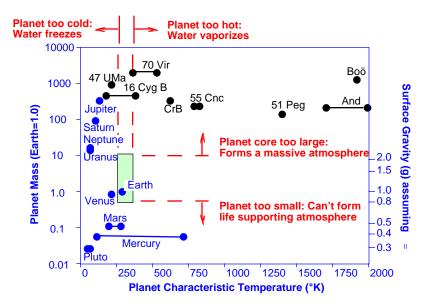


Figure 1 Planet mass and characteristic temperature: The mass and temperature for a planet in the habitable zone is shown by the shaded area. The temperature ranges for the solar system objects are a result of the day-night effects for planets with little or no atmosphere. The temperature fluctuations for the extrasolar objects are due to orbital eccentricities. The surface gravity of an earth-class planet is also shown, assuming a terrestrial density.

liquid water..." At greater than about ten M the body has sufficient mass to attract a massive atmosphere and become a gas giant. At less than about 0.5 M the body does not have sufficient mass to have plate tectonics, which is needed to recycle CO_2 back into the atmosphere 18 .

Based on the above, the habitable zone can be illustrated as shown in Figure 1. Also shown are the mass and characteristic temperature for the planets in our solar system and for the known extrasolar planets. The characteristic temperature is not the surface temperature, but rather the temperature assuming the object is a black body¹⁵. This provides a reasonable approximation, since the values depend on the one-fourth power of the reflectivity and emissivity. Atmospheric composition can strongly effect the surface temperature for a terrestrial planet, as is the case for Venus. Clearly, Earth is the only known habitable planet. The objective of the *Kepler Mission* is to search for earth-class planets in or near the habitable zone.

3. DETECTION METHODS

A detailed description of various planet detection methods can be found elsewhere^{8, 9, 10, 17, 19}. Indirect methods all depend on the planet perturbing the parent star in one way or another: pulsar timing measures the periodic temporal variation in the pulsar period; astrometry measures the periodic spatial shift of the centroid of light from the star; Doppler spectroscopy measures the periodic velocity shift of the stellar spectrum and photometry measures the periodic temporal decrease in brightness due either to a transit or for short-period giant planets the sinusoidal variation in the reflected light. Microlensing measures the one-time only brightness enhancement of some distant star, not the parent star. The direct method spatially resolves the planetary signal from that of the parent star using a coronagraph or interferometric methods to suppress the stellar emission.

4. TRANSIT DETECTION

The transit method for planet detection has been suggested for a number of years²⁰ and its practicality depends on two factors: that the stellar variability *on the time scale of a transit* be less than the decrease in brightness caused by the transit and that the photometric instrumentation has sufficient precision to detect the transit. Three or more transits of a star all with the same period, brightness decrease and duration provide a rigorous method of detection and confirmation. Transit durations will range from four hours for a grazing Mercury-analog to sixteen hours for a central Mars-analog. The brightness decrease is simply the ratio of the area of the planet to that of its star. For a Sun-Earth analog this corresponds to a decrease of one part in 12,000, requiring a space mission due to the limitations introduced by atmospheric scintillation and transparency variations.

For gas giants such as the Sun-Jupiter analog or a 51 Peg analog, ground-based photometry at the milli-magnitude level ²¹ is adequate and a number of groups (High Altitude Observatory, Lowell Observatory and NASA-Ames) are already pursuing this avenue to simultaneously search tens of thousands of stars for transits. Hale and Doyle²² have mounted a campaign to

nearly continuously monitor eclipsing binaries for planets, although objects greater than about 10 M have now been ruled out for the CM Dra system²³.

To detect a Sun-Earth analog the astrophysical and technical issues for a space mission have been resolved, thus making the concept for detection of earth-class planets using photometry practical. These issues include:

- Determining that stellar variability on the time scale of a transit is less than the brightness decrease due to an earth-class transit. This is based on the only data with sufficient precision to demonstrate this, namely that from the SSM-ACRIM-1^{24, 25} and the SoHO missions. These measurements included the UV emission which accounts for about 30% of the variation, but only 9% of the photon flux. The *Kepler Mission* will exclude the UV emission to reduce the effects of stellar variability. The most significant variations are due to spots which rise and set with the rotational period of the star. Most stars in a magnitude limited survey are F-, G- and K-spectral types, as opposed to a distance limited survey where they are mostly M-dwarfs. F-, G- and K-stars have rotation periods similar to our Sun. Thus, the feasibility for detection of earth-class transits for these stars should be similar to what it would be for the Sun-Earth analog.
- The ability to simultaneously and continuously monitor ten of thousands of stars with a required photometric precision of one part in fifty thousand (for a four sigma detection). This requirement can now be met using large-format, thinned, delta-doped, back-illuminated, AR coated, high-speed multiple-amplifier-readout CCDs. Laboratory measurements at NASA-Ames and Lick Observatory have achieved the required precision^{26, 27}. A ground-based experiment using a beam splitter on a telescope has been initiated to demonstrate that the precision can be achieved using a real star field by comparing the amplitudes of each identical star pair from the two beams. Any differences in the pairs should depend only on the instrumental precision and shot noise and not on stellar or atmospheric variations.

The strengths of the transit method include:

- Detect earth-class planets in or near the habitable zone of solar-like stars;
- Detect planets around a wide variety of stars, including earth-class planets around A- and early F-type stars and giants, and planetary cores around B- and A- stars, which have too little spectral structure for the Doppler method to work:
- Detect planets with periods as short as a few days to more than a year;
- Detect planets even as small as Mars if they are in short period orbits;
- Determine the orbit, planet size and characteristic temperature;
- Search beyond the deveral hundred stars near the Sun, which are mostly M-dwarfs, and provide statistics on the abundance of planets in the galaxy;
- Detect planets in both singular and multiple stellar systems;
- Operate in spite of the local or any unknown extrasolar-zodiacal emission;
- Provide results based on many repeatable transits;
- Be implemented immediately, since the technology is in hand.

The only draw back to the method is that the probability for alignment along the line of sight is equal to the stellar diameter divided by the orbital diameter, which for the Sun-Earth analog is equal to one-half percent. Thus ten of thousands of stars must be monitored to detect several hundred planets.

In addition, Doppler spectroscopy can be used to both search for additional non-transiting or longer period giants in the system and to either measure or set an upper limit to the mass of the object detected in transit. Knowing both the mass and size of the planet, its density can be determined. Assuming nearly co-planarity for planetary orbits, about 12% of the cases should show multiple planets in transit²⁸, presuming our planetary system to be typical ²⁹. In the near term, the transit method provides the most practical approach to finding and characterizing a large number of earth-class planets in or near the habitable zone of a wide variety of stars.

5. KEPLER MISSION CONCEPT

The detailed concept for a practical photometric mission to detect earth-class planets has been described previously and refined over the years 20, 30, 31, 32. A number of enhancements include:

- Additional onboard processing;
- Monitoring not just F-, G- and K-stars, but all spectral types in the field of view;
- Inclusion of stars down to fourteenth magnitude rather than just to twelfth; and
- Reducing the photometer mass and switching from a Delta II 7920 to the less expensive Delta II 7425;

These changes increase the anticipated number of earth-class planets detectable from 50 to 480 and also permit detection of short period giants by looking for modulation of their reflected light. We present here an overview of the mission concept in its present state.

5.1 Goals

The scientific goals of the *Kepler Mission* are to detect and determine the characteristics of planets beyond our solar system; a goal stated in *The NASA Strategic Plan*¹⁴. More specifically the mission will determine:

- How abundant earth-class and larger planets are in or near the habitable zone for a wide variety of stars.
- The distances of those planets from their host star.
- The sizes of the planets discovered.
- How often multiple-star systems have planets.
- The albedo, size, mass, density and orbits of giant inner planets.
- The types of stars in general that have planets.

5.2 Number of stars to monitor and breath of planet sizes that can be detected

The probability for a planetary orbit to be aligned along our line of sight to a star is simply the diameter of the star divided by the diameter of the orbit²⁰. Based on the Sun (0.0093 AU diameter)-earth (2AU orbital diameter) analog, planets in the habitable zone have a chance of alignment of about 1/2%. Assuming other systems have two planets of at least the size of the Earth in or near the habitable zone, the probability for detection is about 1%. Planets in orbits less than one AU will have a higher probability. Thus, tens of thousands of stars must be monitored to detect hundreds of planets. Results for shorter period objects will be available early in the mission. For example, objects with orbital periods of a few days to a few months will be detected in a few weeks to less than a year.

Planets smaller than the Earth can be detected around smaller stars and bigger than the Earth can even be found around stars larger than the Sun, e.g., around B- and A-type stars (see Table 2). For shorter period orbits, such as Mercury's, more transits can be observed for a given mission lifetime, thereby enabling detection of even smaller planets for a given stellar size. For example, Mars-sized planets orbiting a solar analog could be detected in a Mercury-like orbit.

For the region of the sky selected (described below) the total number of stars of all spectral classes and luminosity types is 160,000. Taking into account the detectability as a function of the spectral type and brightness calculated in Table 2, the number of main sequence stars brighter than 14th magnitude for which planets can be seen are shown in the Figure 2 for various planet sizes. The number for which earth-class planets ($M \le 10~M$) can be found is 57,000. Potentially many hundreds of planets of various sizes can be found around a wide variety of stars. The median distance for each spectral type of star is also shown.

Table 2 Size dependence of minimum detectable planet, assuming a system sensitivity for detection of a Sun-earth analog and four transits. For each spectral type, the stellar area relative to the Sun and the minimum detectable planet size as a function of stellar brightness is given. System noise is included in addition to shot noise.

	Spectral type											
	B2	B7	A2	A7	F2	F7	<u>G2</u>	G7	K2	K7	M2	M8
Stellar	22.00	9.60	4.00	2.56	1.96	1.44	1.00	0.77	0.61	0.44	0.25	0.01
area												
m_V	Minimum detectable planet radius (Earth radii)											
9.0	4.00	2.64	1.71	1.37	1.20	1.02	0.85	0.75	0.67	0.56	0.43	0.09
9.5	4.03	2.66	1.72	1.38	1.21	1.03	0.86	0.75	0.67	0.57	0.43	0.09
10.0	4.08	2.70	1.74	1.40	1.22	1.05	0.87	0.76	0.68	0.58	0.43	0.09
10.5	4.16	2.75	1.77	1.42	1.25	1.07	0.89	0.78	0.69	0.58	0.44	0.09
11.0	4.27	2.82	1.82	1.46	1.28	1.10	0.91	0.80	0.71	0.60	0.45	0.09
11.5	4.42	2.93	1.89	1.52	1.33	1.14	0.95	0.83	0.73	0.62	0.46	0.09
<u>12.0</u>	4.65	3.07	1.99	1.60	1.40	1.20	<u>1.00</u>	0.87	0.77	0.65	0.49	0.10
12.5	4.94	3.27	2.12	1.70	1.50	1.28	1.07	0.93	0.82	0.69	0.51	0.10
13.0	5.33	3.53	2.28	1.84	1.62	1.38	1.15	1.00	0.88	0.74	0.55	0.11
13.5	5.80	3.84	2.49	2.00	1.77	1.51	1.26	1.09	0.96	0.80	0.60	0.12
14.0	6.38	4.23	2.74	2.21	1.94	1.66	1.38	1.20	1.05	0.88	0.66	0.13
	Giant planets		Planetary cores		Habitable planets , $M \le 10 M$				$M \le 1.3$ Earth			Mars

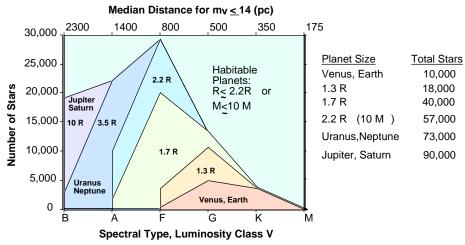


Figure 2 Number and median distance of main sequence stars in the selected FOV for a given minimum planet size and stellar spectral type

5.3 Selected field of view

Since transits only last a fraction of a day, all the stars must be monitored continuously, that is, their brightnesses must be measured at least once every five hours. The ability to continuously view the stars being monitored dictates that the field of view (FOV) must never be blocked at any time during the year. Therefore, to avoid the Sun the FOV must be out of the ecliptic plane. The secondary requirement is that the FOV have the largest possible number of stars. This lead to the selection of a region in the constellation Cygnus looking along an arm of our galaxy where there is a very high concentration of stars. Selecting the FOV to be out of the ecliptic also satisfies the Moon avoidance requirement. Spacecraft in low earth orbit, like the Hubble Space Telescope, must continuously repoint to avoid periodically being blocked by the Earth. Non-polar orbits precess and looking near the pole of an equatorial orbit is well out of the galactic plane. The only solution to this is to launch the spacecraft out of earth orbit. The minimum energy orbit away from the Earth is an orbit about the Sun, similar to the Earth's. With a period just one week longer, the spacecraft will slowly drift from the Earth. After four years, the photometer will be approximately 0.5 AU from the Earth, depending on the variation in the specific impulse of the solid rocket third stage. For the selected FOV a 55° sunshade will keep stray light out of the aperture at all times.

5.4 Photometer description

To make the brightness measurements the requirements on the photometer are:

- Large field of view to monitor 160,000 stars as faint as m_V=14;
- Large enough aperture to reduce photon noise to the level comparable to other factors; and
- Photometric system precision of one part in 50,000 (1).

The photometer will consist of a 12° FOV one-meter aperture Schmidt telescope and twenty-one CCDs (Figure 3) with field flatteners at the focus. The photometer can be and will be fully tested on the ground prior to launch. Each CCD will have $2048x2048\ 24\mu m$ pixels with quad readout and is thinned, back-illuminated, delta doped and AR coated. Arrays of CCDs of this size are already being constructed³³. The system design will permit measurement of the brightness of a $m_v=12$ G2 main sequence star with the specified precision in five hours of integration (Table 2). Each CCD will be readout every three seconds. The images will not be stored. Rather the pixels associated with each one of the 160,000 stars brighter than $m_v=14$ will be co-added and each 3 second readout will be summed over fifteen minutes resulting in an onboard data compression of 165,000:1. These data will be stored, producing $100\ MBytes/day$ of data to transmit.

The key factors utilized to achieve the high photometric precision are:

- Defocusing the star image to seven pixel diameter: This mitigates saturation and sensitivity to motion;
- Controlling the pointing so that each star image remains on the same group of pixels: This eliminates effects of interpixel variations in sensitivity;
- Operating these CCD near full-well capacity: Dark current and read-noise effects become negligible;
- Using relative photometry: The brightness of each star is re-normalized to the average for all stars in each quadrant of each CCD. Each quadrant is readout with a single amplifier;
- That transits only last several hours: Long term photometric stability not necessary; and
- Placing the photometer in a heliocentric orbit: This provides for a very stable thermal and stray light environment.

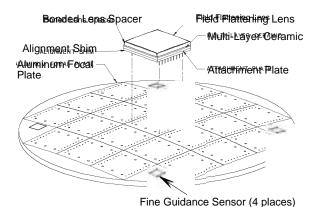


Figure 3 Focal plane assembly: Arrangement of the 21 CCDs at the focus providing a 12° FOV, along with four fine guidance sensors.

Table 2 Noise sources for $m_V=12$ G2-main sequence star for five hour integration

Requirement	Noise			
Shot Noise	1.40x10 ⁻⁵			
Dark Current (<100 e-/pix/s)	0.60×10^{-5}			
Read Noise (<15 e-/pix/read)	0.16×10^{-5}			
Pointing & CCD stability	0.50×10^{-5}			
Crowding & No Shutter	0.20×10^{-5}			
Stellar Variability	1.00×10^{-5}			
Total Noise (RSS)	1.90x10 ⁻⁵			
Single Transit SNR	4.4			

5.5 Spacecraft description

To support the photometer, the spacecraft requirements are to:

- Maintain pointing stability;
- Process and store the scientific data;
- Provide communications;
- Provide power for all of the systems; and
- Provide a stable thermal environment

Figure 4 illustrates the design concept that will meet these requirements. Preliminary concepts have been developed for all of the subsystems including: structural and thermal; command and data management; and attitude determination and control. Power and weight estimates have been developed.

The pointing stability of 0.3 arcsec (3) will be achieved with a combination of fine guidance sensors in the focal plane, sensing gyros and reaction control wheels. Additionally, sun sensors and star trackers will be used for initial acquisition and cold gas thrusters to dump momentum. Being in a heliocentric orbit, the only significant torque on the spacecraft will be caused by the solar photon pressure.

The data from the twenty-one CCDs will be handled by three parallel data processing systems utilizing MIL-STD-1553B bus structure, each handling seven CCDs and producing somewhat less than 100 MBytes of data per day. The spacecraft will have the capacity to store up to three day's worth of data. Communication will be with a X-band transponder having both an omni-antenna and a high-gain antenna with a 2° beam. The 34-m Deep Space Network will be used to communicate with the spacecraft.

Power will be provided by a fixed solar array. The spacecraft will be rolled 90° about the optical axis every three months to keep the solar array azimuth within $\pm 45^{\circ}$ of the Sun. (The focal plane has a 90° symmetry.) The instrument will use 250W and the spacecraft 157W including a total contingency of 67W. The array output will be sized to be 530W at end-of-life.

Thermal control will be achieved using a basically passive design consisting of multilayer insulation, paint, thermal tape, localized radiators and active heaters. The instrument will be thermally isolated from the spacecraft bus. Maintaining the solar vector to within $\pm 45^{\circ}$ of one axis, using the solar array as a thermal shield, having the balance of the photometer always viewing deep space and not having a continuously varying thermal load associated with an earth orbit, greatly simplifies the thermal design and is a major factor in maintaining thermal stability and high photometric precision. Thermal time constants will be long compared to the planetary transit times being measured. Planetary transits are basically an AC phenomena and baseline drifts over weeks and months are not relevant.

The launch mass of the instrument is 350kg and that of the spacecraft 330kg including a total contingency of 105kg. The Delta II 7425 has a capability of launching 800kg to earth escape velocity.

Additional features of the mission design are:

- There are no solar panels or other components to deploy;
- The only moving part is the high gain antenna;
- The many CCDs and multiple parallel processing channels allow for graceful degradation of the instrument;

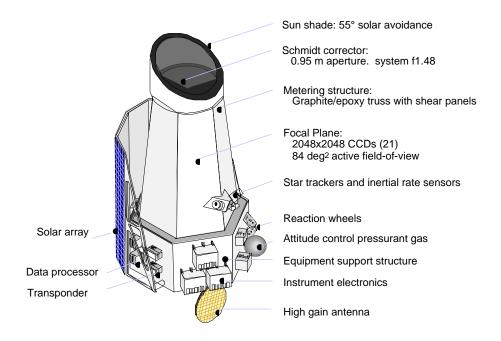


Figure 4 Design concept for the photometer

- Extending the mission lifetime from four years to eight years would allow detection of earth-class planets with orbits of up to two years or observing of other star fields;
- Operational support is minimal since there is only one instrument and the photometer will be pointed at just one place on the sky;
- Guest investigator programs involving astrophysics on selected objects in the FOV can be easily accommodated (such as p-mode oscillations); and
- Scientific data will be posted in nearly real time on the Internet.

5.6 Expected results

If the majority of the 90,000 main sequence stars observed have planetary systems grossly similar to our own solar system then it is anticipated that the *Kepler Mission* would find from transits³²:

- About 480 earth-class planet detections; and
- About 60 cases (12%) of two or more earth-class planets per system.

The primary goal of this mission is to test this hypothesis. Even a null result would be significant, as it would indicate that our understanding of planetary formation must be revised and that earth-class planets must be rare in our galaxy. Doppler spectroscopy could be used to look for any massive companions in these systems. From the period, transit depth and stellar characteristics the following fundamental characteristics can be derived for each individual planet detected:

- The orbital semi-major axis,
- The planet's size,
- The planet's characteristic temperature; and
- The mass and surface gravity (assuming a density).

For planets closer-in, the probability of orbital alignment is greater. For example, the probability averaged over 0.05 to 0.1 AU would be 6.5%, but for planets at 5 AU the probability is down to 0.1%. If the frequency of giant planets with short period orbits is of order 2% 10 and the balance of the systems have giant outer planets, then from transits of these giant planets it is anticipated that the mission will detect:

- About 160 inner-orbit planets (80 for F- and G-stars only), and
- About 24 outer-orbit planets (seen once during four years but with a SNR of 400).

These detections can be followed up from the ground both with photometry to confirm the outer orbit transits seen only once and with Doppler spectroscopy to get their mass provided the spectral type is later than F5 and brighter than $m_V=12$. For the 3400 stars in the FOV that meet these criteria about 0.24% can be observed using both photometry and spectroscopy resulting in:

• Densities for about seven planets.

For the giant planets with orbital periods less than one week, the modulation of their reflected light should be readily detectable given the photometric precision of the *Kepler Mission*. Although the modulation may be as small as 10^{-5} , the sinusoidal nature of the signal and the many hundreds of cycles during the mission allows for a SNR of six for stars no noisier than the Sun. Given that 87% of these close-in giants will have orbital inclinations greater than 30° and that 4% of the 90,000 main sequence stars will have close-in giants, it is expected that from the phase modulation of the reflected light:

- About 1400 giant planets will be detected with periods less than one week (680 for F- and G-stars only), and
- Albedos for the 160 giant inner orbit planets whose size is known from their transit (80 for F- and G-stars only). Finding the albedo will provide important information about the planet's atmospheres.

A by product of this mission will be an enormous amount of astrophysical data on the variability of all spectral-types and luminosity-classes of stars. In addition, ancillary science wherein Guest Investigators would identify other objects within the FOV that would not be otherwise sampled or objects for which higher sampling rates are desired, could be supported. Examples of the kinds of additional scientific results that would come out of the data base are given in Table 3.

Table 3 Astrophysical value of photometry with Kepler Mission³⁴

Stellar Physics	Value				
Stellar rotation rates	Large sample of stars				
p-mode oscillations	Window to stellar interior:				
	Mass, age, He abundance				
Characteristics of solar-type stars	Define what is meant by a "normal star?"				
Frequency of Maunder minimums	Earth climatic implications, paleoclimatology				
Stellar activity	Star spot cycles, white light flaring				
Astrophysics	Value				
Cataclysmic Variables	Pre-outburst activity, mass transfer				
Eclipsing binaries	Frequency of high-mass-ratio systems				
Active Galactic Nuclei variability	"Engine" size in BL Lac, quasars, blazars				

6. SUMMARY

The *Kepler Mission* will provide detection of hundreds of earth-class planets and their characteristics as well as a wide variety of information about hundreds or thousands of giant planets. Results will come in progressive stages: in weeks for 51 Peg analogs; in the first year for earth-class objects in Mercury-like orbits; after four years for earth-class and other objects in or near the habitable zone; and at any time for Jupiter analogs. The *Kepler Mission* will detect, characterize and determine the frequency of earth-class planets for a statistically significant sample of main sequence stars in our galaxy, including multiple star systems and those possibly embedded in significant extrasolar zodiacal emission. As a survey mission it will serve as a forerunner to and help scope the requirements for the targeted missions in NASA's Origins program. The concept consists of a classical one-meter Schmidt telescope using conventional CCDs. The spacecraft has no deployable or moving parts other than the high gain antenna. The *Kepler Mission* is clearly responsive to the fundamental question listed in the *NASA Strategic Plan*: Are there Earth-like planets beyond our solar-system?"

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